

# The dark GRB080207 in an extremely red host and the implications for GRBs in highly obscured environments

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## ABSTRACT

We present comprehensive X-ray, optical, near- and mid-infrared, and sub-mm observations of GRB 080207 and its host galaxy. The afterglow was undetected in the optical and near-infrared (nIR) implying an X-ray-to-optical spectral slope less than 0.3, identifying GRB 080207 as a dark burst. *Swift* X-ray observations show extreme absorption in the host, which is confirmed by the unusually large optical extinction found by modelling our the X-ray to nIR afterglow spectral energy distribution. Our *Chandra* observations obtained 8 days post-burst allow us to place the afterglow on the sky to sub-arcsec accuracy, enabling us to pinpoint an extremely red galaxy (ERO), with  $R-K > 5.4$  ( $g-K \sim 7.5$ , Vegamag) at the afterglow location. Follow-up host observations with the *Hubble Space Telescope*, *Spitzer Space Telescope*, Gemini, Keck and the James Clerk Maxwell Telescope (JCMT) provide a photometric redshift solution of  $z \approx 1.74^{+0.05}_{-0.06}$  ( $1\sigma$ ,  $1.56 < z < 2.08$  at  $2\sigma$ ) for the ERO host, and suggest that it is a massive and morphologically disturbed ultra-luminous infrared galaxy (ULIRG) system, with  $L_{FIR} \sim 2.4 \times 10^{12} L_{\odot}$ . These results add to the growing evidence that GRBs originating in very red hosts always show some evidence of dust extinction in their afterglows (though the converse is not true – some extinguished afterglows are found in blue hosts). This indicates that a poorly constrained fraction of GRBs occur in very dusty environments. By comparing the inferred stellar masses, and estimates of the gas phase metallicity in both GRB hosts and sub-mm galaxies we suggest that many GRB hosts, even at  $z > 2$  are at lower metallicity than the sub-mm galaxy population, offering a likely explanation for the dearth of sub-mm detected GRB hosts. However, we also show that the dark GRB hosts are systematically more massive than those hosting optically bright events, perhaps implying that previous host samples are severely biased by the exclusion of dark events.

**Key words:** Gamma-ray bursts:

## 1 INTRODUCTION

A fraction of gamma-ray burst afterglows are undetected or have suppressed flux in the optical and even in the nIR (e.g. Groot et al. 1998). These bursts may include high-redshift events or where there is significant absorption in the host

galaxy. Alternatively, observational selection effects may result in a non-detection due to unfavourable location, poor weather etc. for ground based observatories. These observational selection effects can largely be avoided by selecting bursts based on some quantitative criteria, in particular by comparing the optical limits on the afterglow emission to the expected values based on the observed X-ray flux and spectral slope. By this criterion Jakobsson et al. (2004) (see

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also Rol et al. 2005) define dark bursts as those with an X-ray-to-optical spectral slope,  $\beta_{OX} < 0.5$ , where  $F_\nu \propto \nu^{-\beta}$  and

$$\beta_{OX} = \frac{\log_{10}(F_{\nu,X}/F_{\nu,Opt})}{\log_{10}(\nu_X/\nu_{Opt})}. \quad (1)$$

In the range  $0.5 < \beta_{OX} < 1.25$  which is suggested by the standard fireball model, the distribution of  $\beta_{OX}$  is approximately flat (e.g. Figure 1 in Jakobsson et al. 2004), with a tail of  $\beta_{OX} < 0.5$  outliers. van der Horst et al. (2009) proposed a more sophisticated approach and define dark bursts by  $\beta_{OX} < \beta_X - 0.5$ . Selecting bursts which are dark by these requirements, ensures the sample studied appears genuinely physically distinct from the optically bright GRBs, in contrast to simple requirement of an optical non-detection, which is often not constraining in terms of physical models of the afterglow (Rol et al. 2005). Understanding these dark bursts, and the physical causes of darkness is important, not only for characterising the diversity of GRBs themselves, but also for establishing their utility as cosmological probes, and in particular as tracers of the global star formation rate.

Since long GRBs are known to be associated with massive stars (e.g. Stanek et al. 2003; Hjorth et al. 2003), we can contemplate an ideal scenario in which there was direct proportionality between GRB rate and star formation rate, allowing the GRB rate to be an immediate measure of the global star formation rate across cosmic history. Two particular advantages of GRBs in this role come from their brightness, allowing them to be seen at the most extreme redshifts (Tanvir et al. 2009; Salvaterra et al. 2009) and their high energy emission, enabling them to be seen through high dust columns. Coupled with this, they select galaxies across the luminosity function (rather than just at the bright end). Hence, GRBs have the potential to infer the star formation rate, largely free from the order of magnitude corrections that other techniques must apply. For example, estimates based on Lyman break galaxies must make corrections to account for missing galaxies at the faint end of the luminosity function (Bouwens et al. 2006; Bunker et al. 2010, e.g.), and dust obscuration (Bouwens et al. 2009; Overzier et al. 2011, e.g.). In contrast, sub-mm searches find the most extreme, dusty examples, but (at least at present) cannot study fainter galaxies, and hence also require large scale corrections to obtain a total star formation rate (Hughes et al. 1998; Blain et al. 1999). In practice however, the promise of GRBs remains to be fulfilled. This is largely due to a combination of incompleteness in the available samples (e.g. Jakobsson et al. 2006; Fynbo et al. 2009) for example because of the difficulty in locating dust obscured GRBs, and because of poorly known environmental effects (such as metallicity, e.g. Wolf & Podsiadlowski 2007; Modjaz et al. 2008) on the GRB progenitors which impact any direct proportionality between GRB rate and star formation rate. An understanding of dark bursts offers a route through both of these problems; by increasing the completeness of GRB samples, the ability to obtain an accurate redshift distribution for the whole of the GRB population currently detected by *Swift* is gained. In tandem, studies of the environments of dark bursts, in comparison with those of bright examples can be extremely valuable in elucidating the impact of environment on GRB production.

It is therefore reasonable to ask how studies of dark bursts can be achieved. GRBs are located in the gamma-rays and subsequently pinpointed by their X-ray afterglows. Although X-ray afterglows in the *Swift* era are ubiquitous, they frequently do not allow detailed study of the burst due to the inability to obtain either absorption spectroscopy of the afterglow, or the unambiguous detection of the host galaxy. Although *Swift* X-ray positioning has been greatly improved by more refined algorithms that determine the satellites pointing using the Ultra-Violet and Optical Telescope (UVOT), The median X-Ray Telescope (XRT) error circle is still  $\sim 1.5$  arcsec, with 90% of bursts being positioned to less than 2 arcsec (Evans et al. 2009) – suggesting that the bulk of GRB host galaxies still can't be unambiguously determined using only X-rays; Purely by chance (e.g. considering the galaxy number counts by Hogg et al. 1997), XRT error circles have  $\sim 15\%$  probability of *randomly* containing a galaxy with  $R < 25$  – roughly the median magnitude of GRB hosts (Hogg & Fruchter 1999), and may contain more than one galaxy comparable to the faintest known GRB hosts –  $R < 29$  (Fruchter et al. 2006). Hence, even the now well refined X-ray positions from the *Swift* X-ray Telescope (Evans et al. 2007) cannot unambiguously locate a host. Although absorption in the X-ray afterglows can provide a clue to the GRB environment via the measurement of hydrogen column ( $N_H$ ), this is one of few constraints that can be obtained from the X-ray afterglow alone. Indeed, in the absence of a redshift, even the rest frame X-ray column cannot be accurately constrained. Although the definition of dark bursts doesn't require an optical afterglow non-detection, (and indeed in many cases the afterglow has been detected), selecting an unbiased sample of dark burst hosting galaxies calls for accurate identification of the host even in cases where the optical afterglow remains undetected. A possible solution to the problem of identifying the hosts is to obtain sub-arcsec astrometric positions, reducing the chance alignment by a factor of  $\sim 10$ , for dark GRBs via their X-ray afterglows. Currently, this is only enabled by the *Chandra* X-ray Observatory, and this is the approach employed here.

A consequence of the relative dearth of dark bursts (per the  $\beta_{OX} < 0.5$  definition rather than simply optical non-detection, also throughout this work) in the pre-*Swift* era and relatively weak constraints which can be obtained from X-ray afterglows alone means that the origins and hosts of dark GRBs remain relatively poorly understood, despite the relatively large number uncovered by *Swift*. It is therefore not entirely clear how the environments (both local and galactic) of dark GRBs differ from those of the optically bright population. The fraction of dark bursts appears to be  $\sim 0.5$  (Melandri et al. 2008; Cenko et al. 2009; Fynbo et al. 2009) with the majority of these being consistent with low to medium redshift events suffering from dust extinction in the host (Perley et al. 2009), while perhaps  $\sim 20\%$  originate from  $z > 5$  (Greiner et al. 2011). This could significantly bias samples based on optical detections of the afterglow. Studying the host population of dark GRBs is therefore a priority in order to understand how they differ from normal bursts and what impact the difference will have on statistical host samples – either by inclusion of dark burst hosts, or by their exclusion. Although the number of dark GRBs with securely identified hosts is still relatively small it is noteworthy that several of other

heavily extinguished bursts hitherto have been associated with galactic environments that are *atypical* of the overall host population: The hosts of GRB 020127 and GRB 030115 are massive extremely red objects (EROs) (e.g. Berger et al. 2007; Levan et al. 2006a), although the  $\beta_{OX}$  values are poorly or unconstrained due to lacking follow-up observations (Fox & Frail 2002; Smith et al. 2005). GRB 051022 has a massive host (Svensson et al. 2010) with large average extinction (e.g. Rol et al. 2007; ?) and GRB 080325 also has a massive host with evidence of significant extinction (Hashimoto et al. 2010). Although this is not an exhaustive list of all dark bursts, in these cases the evidence seems to suggest either unusually red hosts, unusually massive hosts or hosts with very high extinction. It is also interesting to note that, in the sample of 34 GRBs in (Svensson et al. 2010) where stellar masses are estimated from spectral energy distribution (SED) fitting, the hosts of all dark bursts are found to be above the median mass of the sample.

Here we present observations of GRB 080207 and its host, utilizing multiwavelength observations stretching from the X-ray to the sub-mm to identify a host galaxy, and study its properties in comparison to other dark, and bright, GRB hosts.

## 2 OBSERVATIONS

GRB 080207 was discovered by *Swift* at 21:30:21 UT on 7 February 2008. A prompt slew enabled the location of an X-ray afterglow, however no optical afterglow was found in UVOT observations. The burst was long duration with  $t_{90} > 300$ s (at which point the source moved out of the BAT field of view (Stamatikos et al. 2008)).

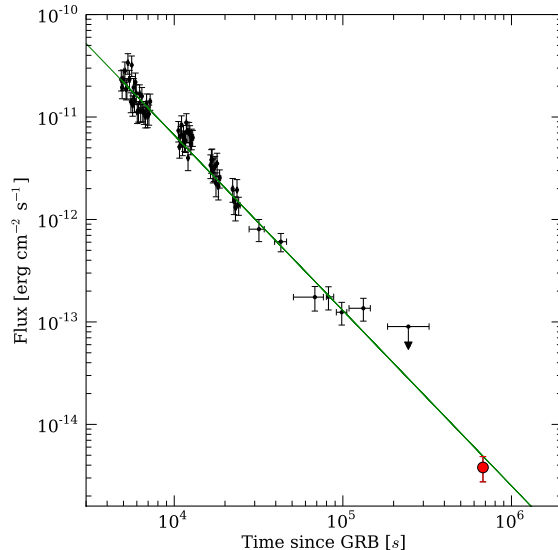
### 2.1 Afterglow

#### 2.1.1 X-ray

Observations with the *Swift* X-ray Telescope (XRT) began 124 seconds after the burst, and continued for 30 hours. For spectral analysis the XRT observations were first processed through `xrtpipeline` to create cleaned event lists in both Window Timing (WT) and Photon Counting (PC) mode. We separately fitted spectra to the WT and PC mode data using `XSPEC`. The WT data are best fitted by an absorbed power-law model with spectral slope  $\beta = 0.34 \pm 0.1$  ( $F_\nu \propto \nu^{-\beta}$ ), and  $N_H = (96 \pm 11) \times 10^{20} \text{ cm}^{-2}$  (assuming zero redshift for the absorption), significantly in excess of the galactic value of  $1.94 \times 10^{20} \text{ cm}^{-2}$ . The PC mode observations yielded a similar excess column density,  $N_H = (75 \pm 16) \times 10^{20} \text{ cm}^{-2}$ , but a much softer spectral slope of  $\beta = 1.4 \pm 0.1$ . It is also worth noting that a consistently high  $N_H$  for the zero redshift case was also found by Racusin (2008).

The WT mode observations took place during the period 130 to 194 s post burst. Throughout this time the BAT was also detecting higher energy emission, and the harder spectral index measured in the WT data is most likely a consequence of the prompt emission in the X-ray band. We therefore adopt the spectral slope of the afterglow as  $\beta = 1.4 \pm 0.1$ , as measured in the PC mode observations.

We took the X-ray lightcurve from the *Swift* repository



**Figure 1.** The X-ray lightcurve of GRB 080207 from *Swift*/XRT PC mode (small black points) and *Chandra* (large filled circle). The *Chandra* flux is rescaled from its observed ACIS bandwidth to equivalent of the *Swift*/XRT in this figure. The solid green line shows a single power law fit with a decay slope  $\alpha = 1.7$ .

(Evans et al. 2007, 2009), to which we added the *Chandra* observation at  $t \sim 7 \times 10^5$  s. The lightcurve is roughly flat during the WT mode observations. The period between the end of WT and the beginning of PC mode observations is broadly consistent with a single power law decay ( $F(t) \propto t^{-\alpha}$ ) of index  $\alpha \sim 1.0$ . There is no sign of, or requirement for steep initial decays, or a later time plateau as seen in many X-ray afterglows (Nousek et al. 2006). The PC mode late time (between 1000 and  $10^6$  s) (Figure 1) is fitted with a single power law with a decay index  $\alpha = 1.7 \pm 0.1$  and  $\chi^2/\text{dof} = 65.36/65 \sim 1.005$ .

*Chandra* observed the afterglow of GRB 080207 on the 16th of February 2008. The afterglow was placed on the AXAF CCD Imaging Spectrometer (ACIS) S-3 (back illuminated) chip and Very Faint (VF) mode employed to enable better rejection of background events. The standard cleaned event files were utilised, but filtered to the energy range of 0.5-7 keV (largely to reduce background events and better isolate the afterglow). The afterglow was detected at a position of RA=13<sup>h</sup> 50<sup>m</sup> 02.98<sup>s</sup>, Dec = 07° 30' 07.4" (J2000) with a 0.5 arcsec error circle. The background subtracted count rate of the afterglow in this band was found to be  $5.3 \times 10^{-4} \text{ s}^{-1}$ . There are insufficient counts in the image to obtain a spectrum directly, however, by assuming the same spectral index as measured in the *Swift* PC mode data this implies a flux of  $3.8 \times 10^{-15} \text{ erg s}^{-1} \text{ cm}^{-2}$  in the 0.3-10 keV band equivalent to *Swift*/XRT, and is consistent to  $\sim 1\sigma$  with the extrapolation of the earlier X-ray lightcurve – indicating that any jet-break has yet to occur 8 days post burst. Alternatively the jet break could have occurred earlier than the onset of the PC mode observations ( $\sim 5000$  s), although this is unusual.

### 2.1.2 Optical

Deep optical observations of GRB 080207 were pursued by several groups roughly 12 hours after the GRB and include observations by 2 to 8 metre class telescopes in both the optical and nIR. None of these observations yielded any afterglow candidates to deep limits. Kuepcue Yoldas et al. (2008) report deep optical limits from the Gamma-Ray burst Optical/Near-infrared Detector (GRON)D:  $g' > 23.9$ ,  $r' > 23.8$ ,  $i' > 23.5$  and  $z' > 22.8$ , nIR limits from the Very Large Telescope (VLT) are reported by Fugazza et al. (2008) as  $J > 23.5$ ,  $H > 22.8$  and  $K > 21.5$ .

These limits are amongst the deepest obtained for emission from any GRB at moderate times after the burst ( $\sim 12$  hours), and were obtained across the optical and nIR waveband by the dual use of multiple 8m telescopes. The deep limits in both the optical and the IR rule out colours similar to that of high- $z$  GRBs like 050814 (Jakobsson et al. 2006), 050904 (Kawai et al. 2006; Haislip et al. 2006), 080913 (Greiner et al. 2009; Pérez-Ramírez et al. 2010; Patel et al. 2010), 090423 (Tanvir et al. 2009; Salvaterra et al. 2009), 090429B (Cucchiara et al. 2011), and also very red colours due to extinction as have been observed in a handful of bursts (e.g. Levan et al. 2006a; Rol et al. 2007; Jaunsen et al. 2008; Tanvir et al. 2008).

## 2.2 Astrometry

To locate the X-ray afterglow precisely on the deep host galaxy images, relative astrometry was performed between the *Chandra* frames and those obtained at the VLT (see Section 2.3). Sources located in the *Chandra* frame were centroided by fitting Gaussian profiles to their light distributions. These were then compared with the VLT Focal Reducer and low dispersion Spectrograph (FORS2)<sup>1</sup> frame (see section 2.3.2), giving a total of 6 optical counterparts to X-ray sources in the optical image. An astrometric solution was computed with the IRAF task `geomap`, which places the afterglow on the FORS2 frame with an accuracy of 0.45 arcsec. Subsequent relative astrometry between the FORS2 and *HST* WFPC2 and NICMOS frames was performed using 10 (WFPC2, F606W) and 7 (NICMOS, F160W) sources in common to each frame. The total error in the placement of the X-ray afterglow on the *HST* images is  $\sim 0.5$  arcsec. We additionally placed the afterglow on our other optical/IR frames (other *HST* filters and instruments, Gemini and Spitzer observations) by performing relative astrometry between NICMOS and those images, the resulting error on these transformations is typically very small ( $\sim 0.1$  arcseconds) and does not contribute significantly to the overall positional error budget.

## 2.3 Host galaxy

At the location of the X-ray afterglow we clearly find a extremely red host galaxy, with  $g = 27.41 \pm 0.3$  and  $Ks = 21.74 \pm 0.13$  (AB-mag, see below for more details).

The probability of a chance alignment of a  $g \sim 27.5$  galaxy is moderate, even within our 0.5 arcsecond error circle, with  $P_{\text{chance}} \sim 0.1$  following Bloom et al. (2002); Levan et al. (2007). However, the probability of an ERO is much lower, indeed, simply utilising the K-band number counts (Conselice et al. 2008) and not accounting for the colours, would imply a probability of  $P_{\text{chance}} \leq 1\%$ . Hence we identify this galaxy as the host of GRB 080207<sup>2</sup>. We have acquired deep observations of the host galaxy host galaxy in 19 bands ranging from observed frame optical B-band to sub-mm 850  $\mu\text{m}$ . The host galaxy is faint or undetected in the optical and bright at longer wavelengths, indicating very red colours not usually associated with GRB hosts. Various images of the field of the host galaxy are displayed in Figure 3. The XRT position (large green circle) is unable to uniquely determine the host, while the improved *Chandra* position (small red circle) intersects three small knots with similar colours, which will be assumed to belong to the host galaxy system.

### 2.3.1 Hubble Space Telescope

The X-ray position of GRB 080207 was observed by the *Hubble Space Telescope* (*HST*) using both the Wide Field and Planetary Camera-2 (WFPC2) in the F606W, F702W and F814W filters, the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) with the NIC3 camera and F160W filter (H-band) and the Wide Field Camera-3 (WFC3) with the F110W filter. Details of the individual observations are reported in Table 2.

The WFPC2 data were retrieved from the archive with “On-The-Fly” processing. The individual images were then cosmic ray rejected, shifted and combined via `multidrizzle` to produce a final image with a scale of 0.06 arcsec per pixel (roughly 2/3 of the native pixel size).

NICMOS images were cleaned for quadrant dependent residual bias levels (pedestal effect) using `pedsky` and subsequently processed through `multidrizzle` onto an output grid with pixel size 0.1 arcsec. WFC3 observations were obtained with a standard 4-point box dither pattern, and also combined via `multidrizzle`, with the native pixel size unchanged (0.13 arcsec).

There is no evidence for host galaxy emission in any of the WFPC2 observations. However, the F160W observations clearly show evidence for a host galaxy at the location of the X-ray afterglow of GRB 080207. Point source limits for objects at the location of GRB 080207 in the WFPC2 images are  $F606W = 26.8$ ,  $F702W = 27.2$ ,  $F814W = 27.0$  (all  $3\sigma$  AB magnitude limits). However, the galaxy is clearly extended in the F160W observations, hence we attempt to derive more realistic limits using apertures equal to the half light radius of the galaxy as measured in the F160W observations (0.4 arcsec), and then assumed this accounted for only 50% of the total galaxy light, hence brightening the limits by a factor of two. In practice the true limiting magnitude depends on the distribution of light within the galaxy, where bright knots

<sup>1</sup> Although tying directly to the *HST* images would have been preferable, this is unfeasible due to the small field of view which contained too few sources in common.

<sup>2</sup> We note that while this paper was in review, a separate paper by Hunt et al. (2011) has appeared. Our precise position confirms their host identification, and their independent discovery of the ERO host.

of emission could often be seen, even if low surface brightness areas were missed. However, these limits are broadly in agreement with the magnitude limits obtained by populating the images with fake sources of half light radii equal to that of the host, and subsequently attempting to recover them via **SExtractor** (Bertin & Arnouts 1996). The resulting limits are F606W=25.4, F702W=25.65, F814W=25.02. (See also Table 2)

### 2.3.2 Ground based host observations

In addition to the optical and nIR observation with *HST*, deep imaging of the host galaxy was obtained with the VLT, Gemini and Keck.

The VLT R-band observation was carried out on the 1st of April 2008, using FORS2. In this image, the host galaxy remains undetected to a limit  $\sim 25.65$ . Although the R-band limit is affected by blending with a neighbouring source, the limiting magnitude is broadly consistent with that from *HST*.

The Gemini imaging was obtained with the Gemini Multi-Object Spectrograph (GMOS) in the z-band, and the Near Infra-Red Imager and spectrometer (NIRI) in J and K. The seeing in the z-band observations was very good ( $\sim 0.5$  arcsec), but was poorer for the J and K band ( $\sim 0.9$  arcsec). These observations were reduced in the standard fashion under IRAF. The host is detected in each of these observations, although only with marginal significance in the J-band observations. Photometry of the host galaxy was performed relative to Sloan Digital Sky Survey (SDSS) observations of the field for the z-band observations, and in comparison to Two-Micron All Sky Survey (2MASS) for the J and K.

The Keck observations were performed with the Low Resolution Imaging Spectrometer (LRIS) in the g- and I-bands. The images were reduced with standard IRAF techniques and zero magnitudes were calibrated relative to SDSS stars in the field. We note that both the g- and I-bands are deeper than the *HST* and Gemini optical observations, resulting in a detection of the host at low wavelength indicating redshift  $z < 2.8$ . The Ks observations provided a factor  $\sim 2$  better signal-to-noise than the Gemini observations in the K-band, and flux consistent within  $1\sigma$ . The Ks-band is calibrated using sources in the field common with the Gemini frame. See Table 2 for a full summary of all observation details and results.

### 2.3.3 Spitzer

The host of GRB 080207 was also observed by the *Spitzer Space Telescope*, utilising both the Infra-Red Array Camera (IRAC) in all 4 bands (3.6, 4.5, 5.8 and 8.0  $\mu\text{m}$ ) and with the Multiband Imaging Photometer (MIPS) at 24  $\mu\text{m}$ . The host is clearly detected in all IRAC and MIPS bands, indicating significant nIR and mIR emission, possibly suggesting a massive and dusty host respectively. The clear detections in these bands are in contrast to the majority of GRB hosts which are undetected (or very weakly detected) in similar observations (e.g. Le Floc'h et al. 2006; Castro Cerón et al. 2008). As the host is unresolved at the resolution of *Spitzer*, photometry of host was performed on the standard post-

basic calibrated data (BCD) mosaics, utilising small apertures (2.4 and 7.4 arcsec for IRAC and MIPS respectively) and applying tabulated aperture corrections and zeropoints. The resulting magnitudes are shown in Table 2.

### 2.3.4 SCUBA2

As a part of the early “shared risk” operations with SCUBA2 (Holland et al. 2006; Economou et al. 2008) on the JCMT, we obtained  $\sim 43$  minutes of observations in the 450  $\mu\text{m}$  and 850  $\mu\text{m}$  bands during the nights 2010-02-25, 2010-02-26 and 2010-03-12. The imaging was carried out in the SCAN mode with a DAISY scanning pattern. The data were reduced using the STARLINK module **SMURF**, running makemap in the iterative mode<sup>3</sup> to map the SCAN data into a sky image with a pixel scale of 3 arcsec (e.g. Jenness et al. 2010). The sky maps are flux calibrated relative to the sub-mm flux of CRL618 which was observed during the same nights as the science observations (e.g. Dempsey et al. 2010). Before the maps for all nights were co-added, astrometric corrections were applied as determined by separate observations of pointing sources obtained during each night. We performed aperture photometry in the 450  $\mu\text{m}$  and 850  $\mu\text{m}$  bands respectively - measuring fluxes  $23037 \pm 17740 \mu\text{Jy}$  and  $2529 \pm 4374 \mu\text{Jy}$  respectively, although the host is undetected. Using blank apertures on the map we estimate  $3\sigma$  limiting magnitudes of 12.1 and 13.6 (AB magnitudes) in the 450  $\mu\text{m}$  850  $\mu\text{m}$  bands respectively, which offer only weak constraints on the sub-mm emission.

## 3 AFTERGLOW PROPERTIES

The X-ray spectrum exhibits apparent absorption significantly in excess of the Galactic value. The preferred zero redshift model results in  $N_H \sim 75 \times 10^{20} \text{cm}^{-2}$  (c.f. total Galactic  $N_H$  column  $\sim 1.94 \times 10^{20} \text{cm}^{-2}$ ) with  $\chi^2/\text{dof} = 125/153$ . Attempting to fit a broken power law with fixed  $\Delta\beta = 0.5$ , e.g. assuming the spectral turn-over to be influenced by a cooling break in the X-ray band, results in significantly worse fits with  $\chi^2/\text{dof} = 168/152$ , and  $36/29$  respectively for PC and WT mode data, suggesting that excess  $N_H$  is the most likely explanation for the observed spectrum.

Grupe et al. (2007) suggest that the X-ray measured  $N_H$  column can be used to limit the redshift by

$$\log(1+z) < 1.3 - 0.5 \log_{10}(1 + \Delta N_H), \quad (2)$$

where  $\Delta N_H$  is the difference between Galactic and observed  $N_H$  values in units of  $10^{20} \text{cm}^{-2}$ , fitted at zero redshift. This would suggest that GRB 080207 originates from  $z < 1.3$ . Interestingly the only GRB in the sample of Grupe et al. (2007) to be found with a higher  $N_H$  than GRB 080207 is GRB 051022, whose optical afterglow was also markedly suppressed (Rol et al. 2007; ?). Indeed, although it is commonly very difficult to assess the redshifts for dark GRBs it is occasionally possible to pinpoint redshifts for bursts whose optical afterglows are somewhat suppressed, and are invisible to UVOT, but are still visible to deep ground

<sup>3</sup> i.e. iteratively fitting detector signal and background noise.

Afterglow properties	
Ra, Dec(J2000)	13:50:02.98, +07:30:07.4
Errorbox	0.5 arcsec
$\chi^2/dof$ (spectral fit)	48.49/48 $\sim$ 1.01
$\beta$	$1.34^{+0.17}_{-0.16}$
$N_H$	$679^{+125}_{-114} \times 10^{20} \text{cm}^{-2}$
$A_V$ (MW law)	$\geq 2.6$
$A_V$ (GRB 080607 law)	$\geq 3.4$
$A_V$ (SMC law)	$\geq 3.7$
$A_V$ (SB law)	$\geq 4.1$
$\chi^2/dof$ (lightcurve)	65.78/66 $\sim$ 1.00
$\alpha$	$1.7 \pm 0.1$

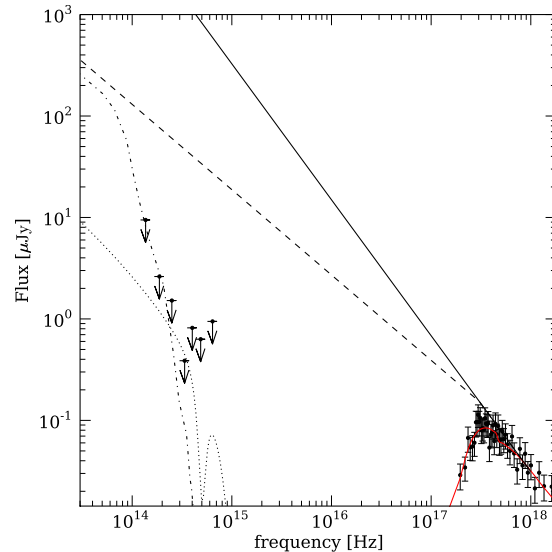
**Table 1.** *Chandra* X-ray position and fitted parameters for the afterglows analysis. The quoted hydrogen column and extinction are calculated in the restframe of the hosts photometric redshift ( $z_{phot} = 1.74$ ).

based optical observations. In these cases the measured (rest frame) column densities are apparently higher than those for the GRBs with very bright optical afterglows (Schady et al. 2007).

Assuming that GRB 080207 is *not* limited to  $z < 1.3$ , we fit the X-ray spectrum with single power law model absorbed by the Galactic  $N_H$  column *and* an absorber redshifted to  $z = 1.74$  as suggested by our photometric redshift solutions for the host (see section 4.1). This model suggests an X-ray spectral slope  $\beta = 1.34^{+0.17}_{-0.16}$  and a significantly higher  $N_H$  column than the zero redshift case with  $N_H = 679^{+125}_{-114} \times 10^{20} \text{cm}^{-2}$ . This makes this one of the highest measured restframe  $N_H$  column of any GRB host yet.

Extrapolating the X-ray power law to optical/nIR frequencies and re-normalising the integrated flux to be consistent to the 11 hour post burst flux suggested by the lightcurve, reveals the optical/nIR flux limits are fainter than expected. The X-ray-to-optical spectral slope is estimated to be  $\beta_{OX} < 0.3$  and thus this burst fulfil the criteria for dark bursts of Jakobsson et al. (2004) (and also fulfils the dark criterion by van der Horst et al. (2009) since  $0.3 < \beta_X - 0.5$ ). To evaluate an optical extinction that explains the optical darkness of this burst, we adopt extinction curves derived for the Milky Way (MW) (Seaton 1979) with  $R_V = 3.1$ ; the Small Magellanic Cloud (SMC) (Prevot et al. 1984) with  $R_V = 2.72$ ; typical starburst galaxies (SB) Calzetti et al. (2000) with  $R_V = 4.05$ ; and the afterglow of the dark GRB 080607 (Perley et al. 2010).

The afterglow model SED is reddened after extrapolating the X-ray into the optical-nIR regime, and after introducing a cooling break with  $\Delta\beta = 0.5$  short-wards of the XRT band (Figure 2). By requiring that the absorbed extrapolation falls below the detection limits, at the redshift  $z = 1.74$  a restframe line of sight extinctions in excess of 2.6 (MW), 3.7 (SMC), 4.1 (SB) and 3.4 (GRB 080607) magnitudes is found. These all suggest that the optical extinction is indeed also very high compared to the bulk GRB population, but that the dust-to-gas ratio is comparable to that found in other hosts (e.g. Schady et al. 2010; Perley et al. 2009). A summary of derived afterglow properties can be found in Table 1.



**Figure 2.** The afterglow spectral energy distribution  $\sim 11$  hours post burst, ranging from nIR to X-ray frequencies. The solid red line shows the X-ray model fitted with redshift  $z = 1.74$ , the solid black line is the X-ray power law extrapolated without a spectral break and the dashed line with a  $\Delta\beta = 0.5$  cooling break. The power law and spectral break model is shown absorbed in the restframe by a Milky Way reddening law with  $A_V = 2.6$  (dotted line), and by a SMC law with  $A_V = 3.7$  (dash-dotted line).

## 4 HOST GALAXY PROPERTIES

The g-band detection of the host galaxy suggests that it lies below  $z \sim 4$ . Coupled with the relatively bright magnitudes in the nIR to mIR, and the red colours across the whole of the wavelength range, rather than a sharp break in the optical and a flat SED in the optical - nIR, the favoured interpretation is that of a dusty sightline. This is also strongly indicated by the detection of the host galaxy at  $24 \mu\text{m}$ , and although the SCUBA2 limits are not deep enough to offer any significant constraints, they are fully consistent with sub-mm dust emission at the photometric redshift  $z \sim 1.7$  we derive in Section 4.1.

The observed lower limit on the colour of  $R - K > 5.4$  (equivalent to  $R - K > 3.7$  in AB magnitudes) is one of the reddest GRB hosts yet discovered, and indicates that, at least in the case of GRB 080207, the environment is markedly different to that of optically bright bursts. The high resolution imaging acquired by the WFC3 on *HST* resolves the large scale structure of the host, which is displaying an irregular morphology, suggesting a merging or disturbed system, possibly crossed by dust lanes.

In the following section we will discuss the photometric redshift solutions and the restframe properties which it implies. The 19 bands covered by photometry are presented in Table 2 and a four band mosaic image in Figure 3 shows the host going from non-detected in the visual, to faint in z-band to strong detections in nIR J-band and IR  $4.5 \mu\text{m}$ . In the following we have assumed a  $\Lambda\text{CDM}$  cosmology with  $\Omega_M = 0.27$ ,  $\Omega_\Lambda = 0.73$  and  $H_0 = 71 \text{ km s}^{-1} \text{Mpc}^{-1}$ .

Host observation log					
Date	Instrument	Filter	Exp.Time (s)	Magnitude (AB)	flux ( $\mu$ Jy)
2009-02-19	Keck/LRIS	g	1640	$27.41 \pm 0.3$	$0.04 \pm 0.01$
2008-03-18	<i>HST</i> /WFPC2	F606W	1600	$> 25.4$	$0.16 \pm 0.10$
2008-04-01	VLT/FORS2	R	2000	$> 25.65^1$	$0.14 \pm 0.07$
2009-03-21	<i>HST</i> /WFPC2	F702W	3600	$> 25.65$	$0.2 \pm 0.08$
2009-02-19	Keck/LRIS	I	1500	$25.84 \pm 0.29$	$0.17 \pm 0.05$
2009-03-20	<i>HST</i> /WFPC2	F814W	3300	$> 25.03$	$0.38 \pm 0.13$
2009-02-24	Gemini/GMOS	z	1260	$25.02 \pm 0.25$	$0.18 \pm 0.05$
2009-02-19	Gemini/NIRI	J	2880	$23.87 \pm 0.31$	$1.06 \pm 0.35$
2009-12-10	<i>HST</i> /WFC3	F110W	2400	$23.32 \pm 0.09$	$1.75 \pm 0.17$
2008-04-05	<i>HST</i> /NICMOS	F160W	2560	$23.04 \pm 0.14$	$2.27 \pm 0.34$
2009-02-19	Gemini/NIRI	K-prime	2880	$21.94 \pm 0.24$	$6.25 \pm 1.62$
2009-05-31	Keck/NIRC	K-short	1500	$21.74 \pm 0.13$	$7.52 \pm 0.93$
2009-03-20	<i>Spitzer</i> /IRAC	$3.6 \mu\text{m}$	1600	$20.81 \pm 0.04$	$17.7 \pm 0.76$
2009-03-20	<i>Spitzer</i> /IRAC	$4.5 \mu\text{m}$	1600	$20.67 \pm 0.03$	$20.14 \pm 0.65$
2009-03-20	<i>Spitzer</i> /IRAC	$5.8 \mu\text{m}$	1600	$20.21 \pm 0.13$	$30.76 \pm 4.32$
2009-03-20	<i>Spitzer</i> /IRAC	$8.0 \mu\text{m}$	1600	$20.63 \pm 0.19$	$20.89 \pm 4.29$
2008-07-31	<i>Spitzer</i> /MIPS	$24 \mu\text{m}$	5407	$18.50 \pm 0.20$	$148.59 \pm 32.1$
2010-02-25,26,03-12	JCMT/SCUBA2	$450 \mu\text{m}$	2616	$> 12.1$	$23040 \pm 17740$
2010-02-25,26,03-12	JCMT/SCUBA2	$850 \mu\text{m}$	2616	$> 13.6$	$2530 \pm 4370$

**Table 2.** Photometric observations of the GRB 080207 host galaxy as part of this work. Magnitude are in the AB system. <sup>1</sup>indicates blending with a nearby source affects the limiting magnitude. Limits in the magnitude column are  $3\sigma$  estimated from half-light radius apertures (WFPC2) or point source limits (SCUBA2). In the flux column, the actual flux measured in the aperture also in the cases of non-detections, are reported.

#### 4.1 Photometric redshift

The 19-band observations cover a broad wavelength range from optical to sub-mm, and should allow a well constrained photometric redshift to be determined, and estimates of the physical properties (e.g. mass and star formation rate) of the host galaxy to be made without relying on extrapolating an assumed spectral shape. To enable detailed and accurate modelling of a system that could possibly contain both a young and starbursting stellar population and an older, redder component we find that allowing for a linear combination of two templates provide a significantly better fit than only using a single template. Hence, to simultaneously fix the photometric redshift and the full restframe spectral energy distribution, we fitted a linear combination of two templates: one coming from a set of detailed optical templates including models described in Coleman et al. (1980) and Bruzual A. & Charlot (1993); and the second set of templates (described by Siebenmorgen & Krügel 2007) containing galaxies with significant amounts of dust increasing their IR and sub-mm luminosities by reprocessing the UV and optical light. Furthermore, we fitted the reddening of the first set of models by assuming a Calzetti et al. (2000) reddening law. The dusty templates in the second set already include a dust screen model, and are not reddened any further. In total this comprises 6 free parameters (redshift,  $A_V$ , two templates and two normalisation constants.), and for 19 photometry data points gives  $dof = 19 - 6 = 13$  degrees of freedom.

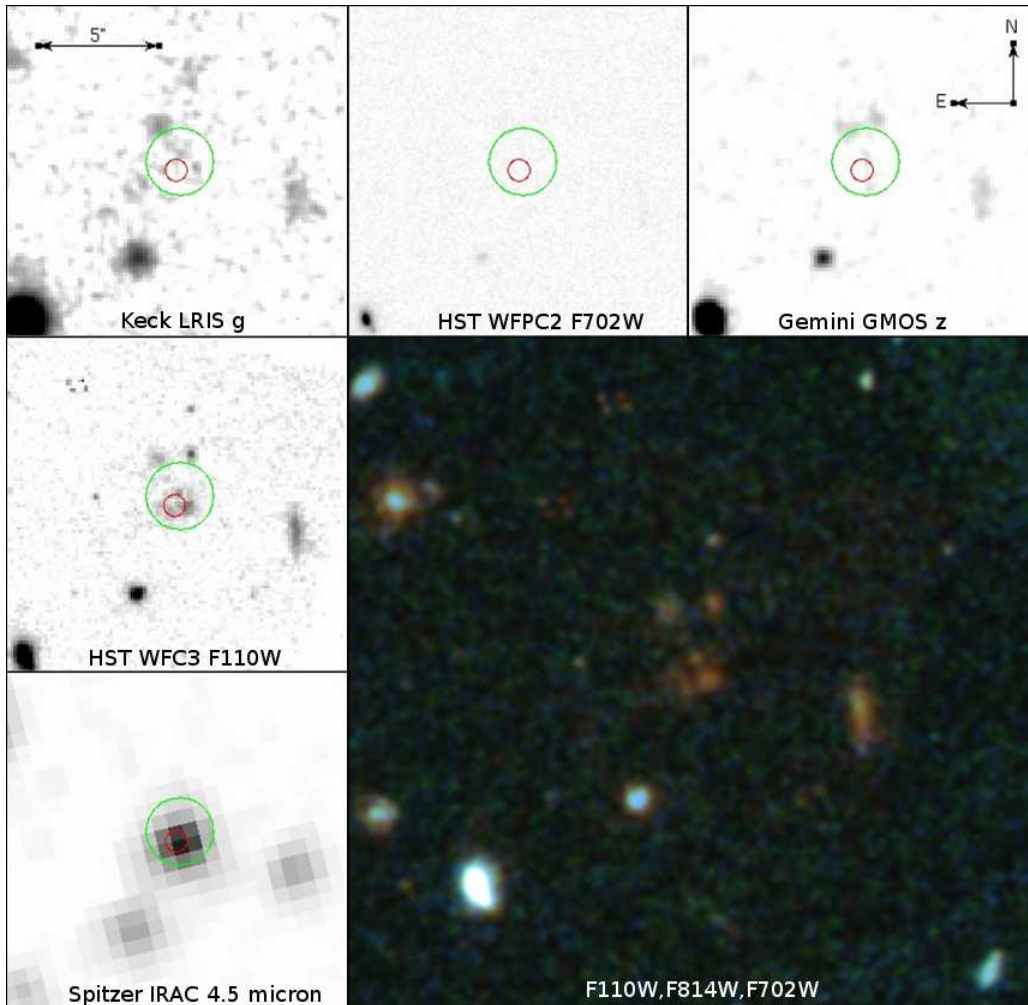
Fitting the available photometry, including measured fluxes for the non detections, and allowing both redshift and host absorption to vary as free parameters (see Svensson et al. 2010) yields a primary photometric redshift solution of  $z = 1.74^{+0.06}_{-0.05}$  with  $\chi^2/dof = 19.37/13 \sim 1.49$ , shown in Figure 4. The redshift error is the central  $1\sigma$  in-

terval, i.e the integrated probabilities above and below the interval are both  $(1 - 0.683)/2$ . This confidence interval is relatively narrow, but somewhat broader at  $2\sigma$ , providing  $z = 1.74^{+0.34}_{-0.18}$ . This result is broadly consistent with an independently derived solution with Hyperz (Bolzonella et al. 2000) using only the optical and nIR photometry. It is also broadly consistent at the  $\sim 1.5\sigma$  level, with the  $z = 2.2^{+0.2}_{-0.3}$  obtained by Hunt et al. 2011, using a smaller dataset. We do not attempt to increase the errors due to possible systematic offsets between different instruments, however note that this would not change our photometric redshift, but (for modest additional errors) would simply slightly increase the confidence ranges. It is also worth noting that a higher redshift than provided by the best fit would further increase the restframe hydrogen column derived from the X-ray spectrum, e.g.  $\sim 10\%$  higher at  $z = 2.2$ . A significantly higher solution is effectively ruled out by the g-band detection.

#### 4.2 Restframe properties of the host

The restframe properties of the host galaxy as derived from these fits are shown in Table 3. We estimated physical galactic properties from the restframe k-corrected and extinction corrected spectral energy distribution. Stellar mass content is estimated from the restframe K band absolute magnitude (Savaglio et al. 2009), corresponding to between IRAC 5.8 and  $8 \mu\text{m}$  at  $z = 1.74$ . For the star formation rate we make two estimates, one based on the U-band luminosity (Cram et al. 1998) and one based on the far-InfraRed (fIR) luminosity (Kennicutt 1998). The host is massive and rapidly star forming - assuming that the fIR traces the true star-formation rate (SFR) more accurately than the U band. Placing it on the  $\frac{SFR}{M_*}$  vs  $M_*$  plane compared to the bulk GRB hosting galaxy population (e.g. Castro Cerón et al.





**Figure 3.** Five band mosaic image of the field of GRB 080207 including its host galaxy (top and left panels). The red circle marks the *Chandra* X-ray position and errorbox, the green circle show the *Swift*/XRT position and error-box. The host is faint or undetected in the optical but shows strong emission in nIR and longer wavelengths. The large lower right panel shows a 3 filter false colour image showing the extremely red host galaxy in the centre and a number of other red galaxies also in the field.

2006, 2008; Savaglio et al. 2009) suggests that it is one of the most massive and most actively star forming GRB hosts to date. From the SED model we estimate a restframe FIR luminosity  $L_{\text{FIR}} \sim 3 \times 10^{12} L_{\odot}$  suggesting that GRB 080207 is one of few bursts with a ULIRG host (Michałowski et al. 2008). However it should be noted that the ULIRG classification rests mainly on the 24  $\mu\text{m}$  MIPS detection, and while the SCUBA2 limits are consistent, they are also too bright to offer significant constraints on the FIR nature of the SED.

Comparing the host with the luminosity function at  $z \sim 2$  (e.g. Dahlen et al. 2005, 2007) suggests that it is comparable to the characteristic luminosity in the B-band;  $L_B \sim 1.3 L_B^*$ , in contrast to the typically under-luminous properties of optically bright GRB selected samples.

In particular, it is clear that the host extinction in this case is high in comparison to the bulk GRB population - the dominant model in the optical has an  $A_V \sim 1.9$  while the second component has a total of  $\sim 100$  magnitudes of extinction from core to surface (see Siebenmorgen & Krügel (2007) for a description of their dust model) - suggestive of a major dust content within the host. Although a  $3\sigma$

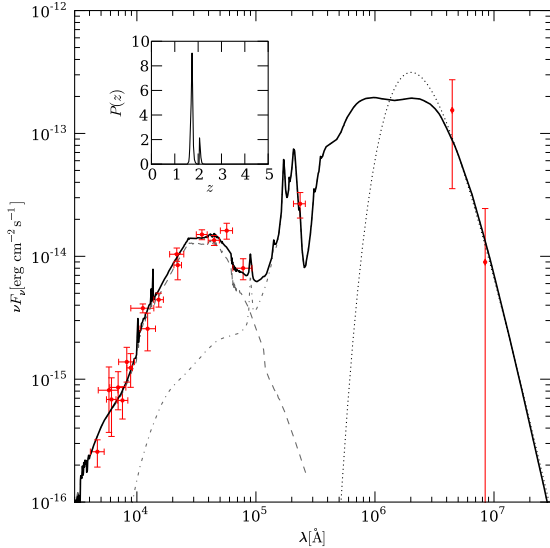
detection is lacking from SCUBA2, we estimate a  $3\sigma$  upper limit of the dust mass as  $\sim 1.2 - 1.4 \times 10^9 M_{\odot}$  assuming a dust temperature of 45 K (e.g. Michałowski et al. 2008), and also note that a lower temperature would increase the necessary dust mass. The possibility of significant dust content is in contrast to the majority of GRB host galaxies, whose photometry suggests relatively little dust (e.g. Savaglio et al. 2009; Tanvir et al. 2004), indeed it is more similar to that commonly found in sub-mm selected galaxies (e.g. Michałowski et al. 2010a). However, it should be noted that these studies have mainly concerned host samples optically selected, and *may not* be representative of the true population.

## 5 DISCUSSION

### 5.1 Implications for dark GRBs

GRB 080207 (see also Hunt et al. 2011) is one of very few GRB hosts which can be classified as an ERO. The





**Figure 4.** The host galaxy spectral energy distribution and photometric redshift solutions at  $z_{phot} = 1.74^{+0.06}_{-0.05}$ . The wavelength scale is in the observer frame. The thick solid line shows the composite template model with the dashed, and dash-dotted lines showing the individual components. The dotted line is purely thermal emission from  $\sim 7 \times 10^8 M_\odot$  dust at  $\sim 45$  K. The inset figure shows the probability distribution as a function of redshift. Errors are  $1\sigma$ .

Host restframe properties	
$z_{phot}$	$1.74^{+0.06}_{-0.05}$
$\chi^2/dof$	$19.37/13 \sim 1.49$
$A_V$	$\sim 1.9$
$M_U$	$-20.29 \pm 0.04$
$M_B$	$-20.99 \pm 0.04$
$M_V$	$-21.86 \pm 0.04$
$M_K$	$-23.89 \pm 0.04$
$L_{fIR}$	$2.4 \pm 0.09 \times 10^{12} L_\odot$
$\log_{10}(M_\star/M_\odot)$	$11.05 \pm 0.02$
$SFR_U$	$40.7 \pm 1.6 M_\odot/\text{yr}$
$SFR_{fIR}$	$416 \pm 17.0 M_\odot/\text{yr}$

**Table 3.** Restframe properties of the hosts SED template fit. Absolute magnitudes are not corrected for host extinction. Stellar mass and star formation rates are corrected for a host internal extinction of  $A_V = 1.9$ . The quoted errors are  $1\sigma$  statistical errors on the best fit template.

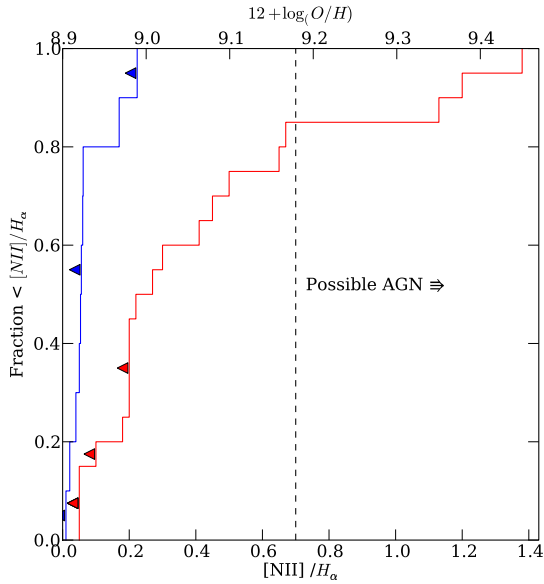
other examples GRBs 030115 (Levan et al. 2006a) and 020127 (Berger et al. 2007) also host bursts which were dark, or showed significant extinction in their afterglow lightcurve. Several other bursts also show very red colours in their afterglows, indicating significant extinction along the line of sight (e.g. Tanvir et al. 2008), however at least in some cases where the afterglow is unusually red, observations of the host galaxies do not reveal exclusively red colours (e.g. Gorosabel et al. 2003a,b; Rol et al. 2007; Jaunsen et al. 2008; Perley et al. 2009; Djorgovski et al. 2001), although there is an apparent trend for the dark GRB

host population to include much redder galaxies than that of the optically bright population (e.g. Hashimoto et al. 2010; Küpcü Yoldaş et al. 2010). Indeed, GRB hosts in general are very blue and typically sub-luminous (Le Floc’h et al. 2003; Christensen et al. 2004), suggesting that only a relatively small fraction of GRB selected star formation is obscured - at least so far as the bulk GRB hosting population is represented by bursts with optically bright afterglows. Further the blue colours of the GRB hosts, and the relatively low detection rate at long wavelength (e.g. Berger et al. 2003; Tanvir et al. 2004) in the pre-*Swift* sample suggest that few GRB hosts are dusty systems, in contrast to sub-mm observations operating in a similar redshift range, which suggest that the bulk of star formation is obscured, with a good fraction occurring in ULIRG-like galaxies (Chapman et al. 2005; Michałowski et al. 2010a).

At first sight then it would appear that the complete set of galaxies hosting GRBs are very different from those of sub-mm galaxies, although the direct comparison is far from trivial (e.g. Watson et al. 2004). Indeed, when comparing the rate of sub-mm detections with that expected under simple models of paucity, sub-mm bright GRB hosts are only marginally ( $\sim 2\sigma$ ) below the expected values (Tanvir et al. 2004; Le Floc’h et al. 2006). Though it should be noted that the sample of sub-mm observations of hosts is relatively small, and that this host sample had a median redshift  $\sim 1.2$  compared to the median redshift of sub-mm galaxies  $\sim 2.2$  (Chapman et al. 2005)

An alternative approach is to study the optical/IR properties of both GRB hosts and sub-mm galaxies. The median I-K colour of sub-mm selected galaxies is  $I-K = 4.1 \pm 0.2$  (Smail et al. 2004), much redder than the general field population which has median  $I-K = 2.8 \pm 0.1$  (Smail et al. 2004). In contrast the GRB population is typically very blue (if somewhat heterogeneously selected to date), with mean colours for optically bright bursts of  $I-K = 1.6 \pm 0.3$ , based on the sample of Savaglio et al. (2009), although a significant fraction of GRB hosts are undetected in deep K-band observations, implying at times even bluer colours.

The mean ratio of  $[\text{N II}] / \text{H}\alpha$  in sub-mm galaxies at  $z \sim 2$  is of order 0.5 based on deep IR spectroscopy (Swinbank et al. 2004), in contrast the (relatively local) GRB hosts with the same measure yield  $[\text{N II}] / \text{H}\alpha \sim 0.1$  (Savaglio et al. 2009; Levesque et al. 2010a). This suggests that even at  $z \sim 2$ , where the universal metallicity may have dropped significantly, sub-mm bright galaxies may not be the most promising locations for GRBs. Indeed, the highest  $[\text{N II}]/\text{H}\alpha$  ratio in the optically bright GRB sample of  $\sim 0.2$  would only include approximately  $\sim 20\%$  of the sub-mm sample of Swinbank et al. (2004) as shown in Figure 5. Although few hosts of dark bursts have direct measurements of their metallicities, making a direct comparison difficult, we note that the dark GRB 020819 has the highest measured  $[\text{N II}]/\text{H}\alpha$  so far reported (Levesque et al. 2010b), suggesting the corresponding distribution for dark bursts includes metallicities at least  $\sim \times 2$  higher. Future observations of the  $[\text{N II}]/\text{H}\alpha$  ratio in GRB hosts at higher- $z$  (for example in the IR with X-shooter), should enable firm statistical statements to be made. In the meantime, we can discuss the host mass distribution which provides a rough proxy for the metallicity distribution.

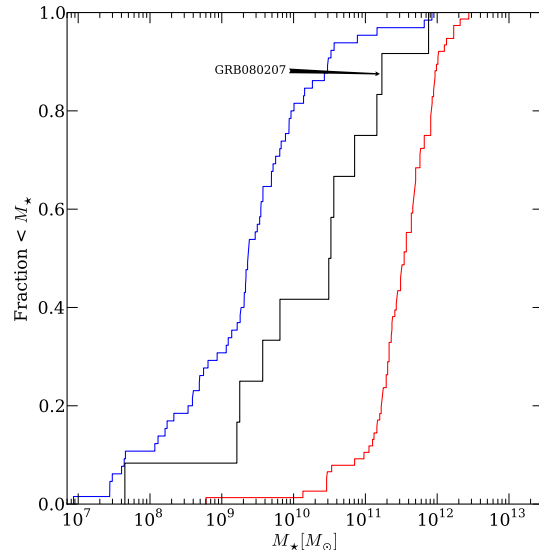


**Figure 5.** Cumulative distributions of the  $[NII]/H\alpha$  ratio for low redshift ( $z < 0.7$ ), optically bright GRB hosts (blue) in comparison to  $z \sim 2$  sub-mm galaxies (red). Triangles indicate upper limit measurements. Sub-mm galaxies with  $[NII]/H\alpha > 0.7$  may have AGN contribution. All galaxies with  $H\alpha$  restframe  $FWHM < 1000 \text{ km s}^{-1}$  from Swinbank et al. (2004) have been included.

## 5.2 The mass distribution of dark burst hosts

In order to further understand the relations between the dark burst hosting galaxy population and ULIRG / sub-mm like galaxies, we compare the stellar mass distributions of sub-mm galaxies calculated by Michałowski et al. (2010a,b) with the stellar masses of dark burst hosts (see Table 4) and the optically bright bursts to redshift  $z < 4$ . We also estimate the sub-mm galaxy masses with our own SED fitting code, and note that results are consistent with the adopted values. The cumulative mass distributions are shown in Figure 6. While it is important to note that the host sample of dark GRBs consists of only 11 galaxies, the results clearly show that dark bursts are systematically hosted by the most massive systems compared the optically bright GRBs. The formal probability that the samples of optically dark and optically bright bursts are drawn from the same population is given by the Kolmogorov-Smirnov (KS) test, where  $P_{KS} = 0.009$ . The contrasting host masses between optically bright and dark bursts is particularly interesting as it lends further credibility to claims that samples based primarily on bursts with optically detected afterglows could be severely inhibited by selection effects (e.g. Fynbo et al. 2009).

Although we have not been able to reach a detection of the host sub-mm flux by SCUBA2, the number of GRB hosts with significant dust content can roughly be estimated. Assuming that some fraction of dark bursts occur in obscured systems, and also have similar dust to mass ratios – we compare their stellar mass distributions in Figure 6. Roughly estimated,  $\sim 90\%$  of the dark burst hosts are more massive than the least massive sub-mm galaxy – and hence under this simple argument one could expect a similar de-



**Figure 6.** Cumulative distribution of stellar mass in optically bright GRB host galaxies (blue line) and hosts of dark bursts (black line). For a comparison we also show the distribution of stellar masses of the sub-mm galaxies (red line) calculated by (Michałowski et al. 2010a,b)

GRB	$z$	$\log_{10}(M_*/M_\odot)$	Ref. (mass or photometry)
970828	0.958	9.57	Svensson et al. (2010)
000210	0.846	9.21	Svensson et al. (2010)
020819	0.41	10.52	Svensson et al. (2010)
050223	0.59	9.81	Svensson et al. (2010)
051022	0.807	10.49	Svensson et al. (2010)
060210	3.9	10.56	Perley et al. (2009)
061126	1.16	11.16	Svensson et al. (2010)
061222	2.08	7.65	Perley et al. (2009)
080207	1.74	11.05	this paper
080325	2	10.85	Hashimoto et al. (2010)
080607	3.036	11.88	Chen et al. (2010)
090417B	0.3	9.25	Holland et al. (2010)

**Table 4.** Stellar masses of all host galaxies of dark bursts available to date. Note that in the case of GRB 090417B we have supplemented the existing data with additional photometry and derived new stellar mass estimates.

tection rate of dark GRB hosts in the sub-mm at SCUBA sensitivity. Depending on the intrinsic mass function of the sub-mm population, even greater detection rates could be plausible with SCUBA2 and even with short integrations with ALMA when considering that the sub-mm galaxy sample in this comparison is flux-limited (Chapman et al. 2005). In terms of physical properties of the dark burst hosts, this suggests that dark bursts are hosted predominantly by a very dust rich galaxy population.

Given that GRBs trace (at best) a fraction of star formation, potentially even at moderately large redshift it is surprising that attempts to transfer directly between GRB rate and star formation rate produce even moderately con-

sistent results (e.g Price & Schmidt 2004; Yüksel et al. 2008; Kistler et al. 2009). Although the sample of dark bursts to date with detected and studied host galaxies is still small, the emerging picture suggests that they indeed trace a different galaxy population than the optically bright sample. Certainly the host of GRB080207 is more akin to sub-mm or ULIRG galaxies than to the typical GRB hosts, suggesting that it is part of a subset of the GRB hosting galaxy population that trace star formation in more massive, dusty and metal rich environments. In the face of the growing evidence that dark bursts can be hosted at higher metallicity than the bulk GRB population studied today, it should be considered likely that GRBs can offer significant advantage over other methods to study the evolution of the cosmic star formation history – but only by paying due attention to sample selection effects and understanding the dark burst host population to avoid bias effects.

Although there is no direct measurement of the metallicity of the host of GRB 080207, the high stellar mass is suggestive of a metal enriched environment – again raising the question of what is the nature and metallicity dependence of GRB progenitors? Considering the low metallicities typically associated with the bulk of the GRB hosts, we note that several authors (e.g. Levan et al. 2006b; Davies et al. 2007) have discussed tight binary systems as possible progenitors to GRBs in high metallicity environments. While this would still require ongoing star formation and high mass stars, Haberman et al. (2010) report evidence for top-heavy IMFs in merging systems, increasing the likelihood of a GRB progenitor.

If the galaxy hosting GRB 080207 is undergoing a merger that further increased its rate of forming massive stars, and if a binary progenitor is indeed possible at high metallicity - maybe massive and dust-rich galaxies are hosting a non-negligible fraction of bursts. Although to which extent these conclusions can be generalised to other dark bursts is far from certain.

## 6 SUMMARY

We have studied the afterglow of the dark GRB080207 from X-ray to nIR wavelengths and presented evidence of significant extinction in excess of at least 2.6 magnitudes (MW law) in the restframe visual as the cause of its optical-nIR darkness. The high optical extinction is also echoed by the restframe hydrogen column which is the highest measured in any GRB environment to date. Lacking optical detection of the afterglow we have used observations of the X-ray afterglow at late time with *Chandra*, enabling an X-ray position to accurately identify the host galaxy. The ERO host spectral energy distribution has been studied in 19 bands from optical to sub-mm allowing us to estimate a photometric redshift  $\sim 1.74$  and an average optical extinction of  $A_V \sim 1.9$  in a massive galaxy. Furthermore, the host appears to be a ULIRG from its FIR SED, with a high star formation rate as traced by the FIR light. With a significant fraction of all bursts being classified as dark, and an increasing desire to utilise GRBs as high redshift probes of the star formation evolution, the understanding of the nature of dark bursts should be highlighted. This, and a number of other dark bursts in similar hosts should further encourage the study

of dark bursts, their host environments and how they relate to the evolving rate of star formation.

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